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METHOD FOR VERIFYING RET LATENT IMAGE SENSITIVITY TO MASK MANUFACTURING ERRORS

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Background

The present invention generally relates to photolithography, and more specifically relates to yield prediction tools for mask quality specifications.

Making a semiconductor device, such as an integrated circuit (IC), involves using photolithography to form patterns on a wafer, where the patterns correspond to complex circuitry. During the process, the patterns are initially formed on a reticle or mask, and then the patterns are exposed on the wafer by shining a light through, or illuminating, the mask.

A mask is typically a transparent silica (quartz) which contains a pattern, wherein opaque regions on the mask are formed of an ultraviolet light-absorbing layer, such as iron oxide. Typically, the pattern is created by a computer-controlled electron beam driven by the circuit layout data, using pattern generation software. A thin layer of electron beam sensitive material called electron beam resist is placed on the iron-oxide-covered quartz plate, and the resist is exposed by the electron beam. A resist is a thin organic polymer layer that undergoes chemical changes if it is exposed to energetic particles, such as electrons or protons. The resist is exposed selectively, corresponding to the patterns that are required. After exposure, the resist is developed in a chemical solution. The iron oxide layer is then selectively etched off in plasma to generate the appropriate patterns.

Depth of focus (DOF) indicates the range of distances around a focal plane where the image quality is sharp. It is important to optimize the illumination of a mask to achieve maximum common DOF, as this results in the best exposure of the wafer. Mask error factor limits the amount of a common process window which is useable.

Optical Proximity Correction (OPC) is common in the industry and involves the pre-compensation of predicted defects of a circuit design. Using empirical data, OPC software creates a mathematical description of the process distortions. Once this description is generated, automated software changes the shapes of the polygons in the pattern layout databases (libraries), moving segments of line edges and adding features that compensate the layout for the distortions to come. The critical layers of the photomask set can then be made using these modified, "pre-distorted" layout designs. When these masks are used to make chips, these predistortions will cancel the process distortions, resulting in better pattern fidelity, higher yield, and enhanced chip performance. Figure 1 shows a pattern (i.e., polygon) 10 pre-OPC, and Figure 2 shows the pattern post-OPC. As shown, OPC results in fragmentation 14 of the edges 12 of the polygon (i.e., to compensate the layout for distortions expected to come). After the edges 12 of the polygons are fragmented, post-OPC assembled masks are usually transformed (i.e., fractured) into a set of small primitives 16 before being passed to a mask vendor. This can be shown in the progression from Figure 2 to Figure 3.

Despite OPC, mask manufacturing process induces statistical errors, which can cause wafer yield loss (the loss sometimes being referred to as "mask error induced wafer yield loss"). Currently, there is a lack of adequate yield prediction tools for mask quality specifications. The approach currently used to attempt to solve the problem involves common process window analysis. However, common process window analysis is limited to a small set of features, and is not practical for full chip application. Furthermore, common process window analysis is not accurate with regard to predicting mask error induced wafer yield loss.

Objects and Summary

An object of an embodiment of the present invention is to provide a method for verifying reticle enhancement technique latent image sensitivity to mask manufacturing errors.

Another object of an embodiment of the present invention is to provide an adequate yield prediction tool for mask quality specifications.

Briefly, and in accordance with at least one of the foregoing objects, an embodiment of the present invention provides a method which includes the steps of revising a polygon based on mask CD distributions to provide a virtual mask, imaging the virtual mask to obtain image statistical parameters, and comparing the statistical parameters to design rule requirements.

More specifically, the method may include the steps of simulating an aerial and/or latent image of the virtual mask, calculating response functions based on the simulated image, collecting measurements and calculating statistical parameters based on the response functions, and comparing the statistical parameters with design rule requirements (i.e., for DI yield percentage for required mask manufacturing specification).

The virtual mask is obtained by using mask CD distribution to induce statistical variations to layouts which have passed through the conventional OPC procedure. For example, fragments of the polygons may be moved (either inside or outside) based on a randomly generated number from assumed (or vendor provided) mask CD distribution.

This approach is believed to be the most beneficial implementation with regard to full OPC flow procedure. Alternatively, the primitives can be re-sized (either by expansion or shrinkage) depending on the mask CD distribution. This approach is beneficial for applying to fractured data or to final post OPC mask, wherein data volume is sufficiently increased by fracturing into primitives.

Brief Description of the Drawings:

The organization and manner of the structure and operation of the invention, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in connection with the accompanying drawing, wherein:

Figure 1 illustrates a polygon before OPC;

Figure 2 illustrates the polygon after OPC, wherein edges of the polygon have been fragmented;

Figure 3 illustrates the shape of Figure 2, after it has been transformed into a set of small primitives;

Figure 4 provides a flow chart which illustrates a method which is in accordance with an embodiment of the present invention; and

Figure 5 provides a block diagram of a yield prediction tool for mask quality specifications, wherein the tool can be used to practice the method illustrated in Figure 4, and wherein the tool is in accordance with an embodiment of the present invention.

Description

While the invention may be susceptible to embodiment in different forms, there are shown in the drawings, and herein will be described in detail, specific embodiments of the invention. The present disclosure is to be considered an example of the principles of the invention, and is not intended to limit the invention to that which is illustrated and described herein.

Mask quality parameters such as across reticle CD distribution affect wafer DICD or printability yield (i.e., "below DI yield"), or post-etch wafer FICD (i.e., "below FI yield"). (Everything is applied to FI-yield , the method is not limited by the only DI-yield calculation). The parameters needed to control mask quality for acceptable DI yield is determined by the reticle enhancement technique (RET) used for improving wafer printability. The more stringent the requirements for mask quality control, the higher mask cost. Statistical analysis of the wafer DICD/print quality response (i.e., distributions) to the random variations of reticle control parameters can be used for studying the tradeoffs between mask quality and wafer performance in order to determine cost effective mask specifications for optimum DI yield.

Figure 4 illustrates a method which is in accordance with an embodiment of the present invention. Specifically, Figure 4 illustrates a method for verifying reticle enhancement technique latent image sensitivity to mask manufacturing errors.

As shown in Figure 4, the method includes the steps of revising a polygon based on mask CD distributions to provide a virtual mask, working with the virtual mask to

obtain response function statistical parameters from the mask image, and comparing the statistical parameters to design rule requirements.

More specifically, the method preferably includes the steps of simulating an aerial and/or latent image of the virtual mask, calculating response functions based on the simulated image, collecting measurements and calculating statistical parameters based on the response functions, and comparing the statistical parameters with design rule requirements (i.e., for DI yield percentage for required mask manufacturing specification).

The virtual mask is obtained by using mask CD distribution to induce statistical variations to layouts which have passed through the conventional OPC procedure. For example, for statistical analysis, before the mask assembly step, edges of the polygons (identified with circles 20 in Figure 2) may be moved (either inside or outside, as represented by the double arrow 22 in Figure 2) based on a randomly generated number from assumed (or vendor provided) mask CD distribution. This approach is believed to be the most beneficial implementation with regard to full OPC flow procedure. Alternatively, the primitives (see Figure 3) can be re-sized (either by expansion or shrinkage) depending on the mask CD distribution. This approach is beneficial for applying to fractured data or to final post OPC mask, wherein data volume is sufficiently increased by fracturing into primitives.

Once the virtual mask is generated, a simulated image is formed of the virtual mask, the CD or 2-D area is calculated (i.e., "response functions"), measurements are collected, and statistical parameters for CDs and 2-D area are calculated (such as mean, standard deviations, maximum, minimum, etc.). Then, the response functions are compared with design rule requirements for DI yield percentage for required mask manufacturing specifications.

The most relaxed distributions of the reticle control parameters (i.e., greater standard deviations, range, etc.) which produces wafer control parameter distributions within acceptable range, by technology design rule specifications, is the optimum reticle specification requirement to comply with.

Figure 5 is self-explanatory and illustrates a yield prediction tool for mask quality specifications, wherein the tool can be used to practice the method illustrated in Figure 4, and wherein the tool is also in accordance with an embodiment of the present invention. The tool may be implemented in software, hardware, or a combination thereof.

While embodiments of the present invention are shown and described, it is envisioned that those skilled in the art may devise various modifications of the present invention without departing from the spirit and scope of the appended claims.